

CO₂ Capturing Plant for Greenhouse Gas Reduction

Project Description:

A new DOE report on greenhouse gas emission scenarios predicts that by 2100 global CO₂ emissions can be tripled leading to worldwide disastrous consequences [1]. Stabilization can be enhanced via capturing the excess of CO₂. To extract post combustion CO₂, existing technologies are utilizing flue gas from fixed CO₂ sources such as power plants. Nearly \$30 per ton of CO₂ released has been assigned by the European Union in a cap and trade CO₂ system and the value of these is expected to rise as cap levels are periodically reviewed. There is a general expectation that the US will adopt a similar system as concerns over greenhouse gas emissions and their effects on the environment and our standard of living increase. Once the fees will be required by the state, California electricity rate payers will bear the cost burden when electricity producers are forced to purchase these credits when they exceed the emissions caps. These costs could be offset if the utilities efficiently capture and sequester CO₂. One possibility is to remove CO₂ from the power plant effluent and transport the CO₂ to an acceptable sequestration site. However, current CO₂ capture technologies are energy inefficient and increase the cost of electricity production by up to 80% [2]. Alternatively, power plants could be constructed at locations suitable for sequestration to avoid the CO₂ storage, pipeline and/or shipping costs. However, these sequestration sites are likely to be in remote locations not ideal for electricity generation. We propose an *attractive alternative* which involves the extraction of post combustion CO₂ from sources such as industrial or transportation, directly from the atmosphere at the sequestration site. Co-locating the two eliminates the cost of transportation and storage of CO₂. The atmosphere provides the “free transportation”. In this way also, the CO₂ extraction facility could be sized for continuous average production rather than peak production as the atmosphere provides the buffer storage.

Since there is no such existing technology, we propose to invent a revolutionary energy efficient, low cost, CO₂ capturing units that can supply high volumes of post combustion, atmospheric CO₂ in an optimum location for underground sequestration. In a different application, the extracted CO₂ can also serve as a source for industrial processes such as methanol production. Methanol has a high potential of becoming a common source of energy, thus replacing fossil fuels and ending political related issues surrounding oil. Figure 1 shows a diagram outlining the proposed system.

To concentrate vast amounts of CO₂ larger than 30,000 tons/day directly from the atmosphere (such as emitted by the fuel combusted from a median sized refinery or power plant) enormous area membranes are required. Our goal is to develop a large area membrane that can be packaged in a compact configurations thus shrinking the actual system size by orders of magnitude and enabling efficient large volumes of CO₂ capture.

Another goal is to drive down the cost of our revolutionary extraction system to be competitive with flue gas extraction. Palo Alto Research Center's wide experience in large area displays will be utilized in developing such cheap and large area capturing technology. In addition, we aim at reducing the costs by increasing the energy efficiency of the concentrator cell. Proposed efficiency improvements paths are via materials optimization of the various capturing cell compartments and can be developed in our labs.

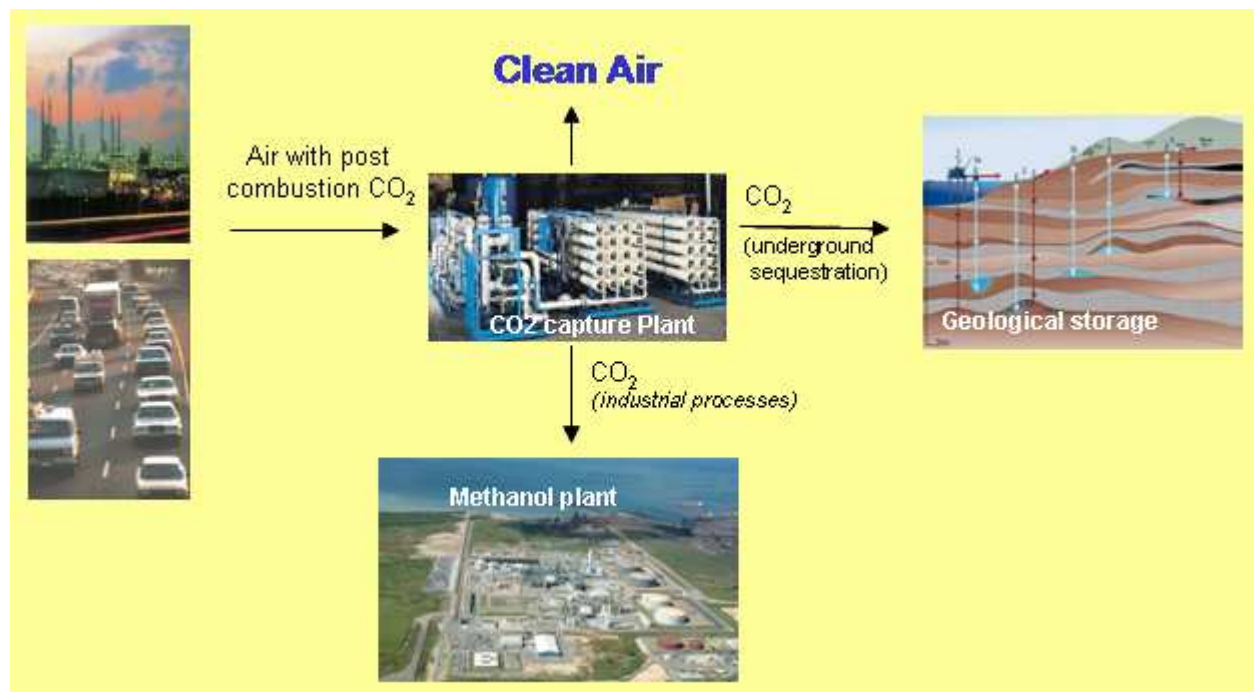


Figure 1: schematic diagram of the proposed CO₂ capturing concept.

Emission reduction calculations and assumptions:

CO₂ emission calculations for carbon capture plant sizing:

A median US refinery processes 80,000 bbl of oil every day (<http://www.eia.doe.gov/neic/rankings/refineries.htm>). One barrel of oil, when converted to fuel and combusted, creates about 400 kg of CO₂. Such a refinery processes enough oil to make over 30,000 metric tons of CO₂ every day. An effective carbon capture and sequestration plant should be sized to offset approximately this CO₂ emissions burden.

Daily emission reduction via CO₂ capturing plant:

One CO₂ capturing plant is sized to capture and sequester approximately 30,000 tons CO₂ /day via an electrochemical process by passing air over a membrane assembly with an internal surface area of 50km². Capturing assumptions are based on the results of a small scale prototype [see ref 3]. The large area required in this case, will be split into ~1300 coiled cylinders using our proposed revolutionary rolled membrane technology and will reduce the required land area to less than 0.2km².

CO₂ capture membrane cylinder size calculations:

A membrane cylinder 10m tall (R=5m), 5m long, and with 1cm membrane spacing will contain ~38,000m² of rolled membrane. To pack 50km² of a membrane, we need 1315 of such cylinders. This number of cylinders will fit in a CO₂ capturing plant with land area of 0.13 km² and in about 0.2km² when spacing for equipment such as pipes, fans and others is included.

2020 emission reduction:

2020 baseline emission assumed (following the ARB 2004 estimate) is 496.95*10⁶ tonsCO₂/year (http://www.arb.ca.gov/cc/ccei/inventory/tables/rpt_inventory_ipcc_all.pdf)

2020 emission targets are comparable to those of 1990 = 436.19*10⁶ tons CO₂/year (based on targets from the CA executive order #S-3-05).

$$\% \text{ reduction} = \frac{496.95 - 436.19}{496.95} \cdot 100 = 12.22\%$$

To reach the 2020 emission targets, 60.76*10⁶ tons CO₂/year need to be removed or 166,465 tons/day.

$$\frac{166,465 \text{ tons} / \text{day}}{30,000 \text{ tons} / \text{day}} \approx 6$$

This could be accomplished with 6 CO₂ capturing plants.
Each plant would account for a 2.2% reduction in CO₂ emission.



Cost effectiveness calculation and assumptions:

Assumptions:

A preliminary cost calculation of a CO₂ extraction plant includes the sum of the following components:

- Capital expenses (for a CO₂ capturing plant)
- H₂ cost
- CO₂ injection and storage
- Recaptured electricity

Capital expenses: The capital expenses for building one CO₂ capturing plant including equipment, operation and maintenance (10 years) are estimated at the \$1B range, or ~\$5/tonCO₂ (driven mostly by the cost of the carbon capture membrane material at \$10/m²)

H₂ costs: The CO₂ capturing system is comprised of an electrochemical cell where standard air containing CO₂ is passed across the cathode side of the membrane and H₂ is diffused over the anode side. H₂ is consumed driving the extraction of CO₂ from the air. H₂ costs dominate the operations cost of carbon capture. Current and future H₂ pricing (\$3.2/kg today, \$1.9/kg predicted for 2017 based on DOE estimates) are included in the calculations. These H₂ prices also include capital, operation, and maintenance expenses for the H₂ generation systems [4].

Faradaic efficiency: A small scale prototype of a CO₂ extraction unit [3] with 20% Faradaic efficiency has been demonstrated. Our proposed cell efficiency targets 100%. Cost effectiveness scenarios will be demonstrated for both cases.

CO₂ pumping costs: To sequester CO₂ at the capture site we assume \$5/tonCO₂ as the injection and storage costs.

Recaptured Electricity: The CO₂ capture reaction is accompanied by the generation of electrical energy which can be sold back to the grid and offset some of the unit operating costs. To calculate the recaptured electricity, we assume 0.5 V cell potential and 6 cents per kW-hr.

Current sequestration costs and offsets: Estimated sequestering costs for coal fired power plants, gas fired power plants, and other industrial sources range from \$15/tonCO₂ to \$115/tonCO₂ captured [2] not including transport (1-8\$/tonCO₂ per 250km), injection and storage costs. Our proposed CO₂ capturing unit cost must be competitive or cheaper if it is to offset power plant CO₂ emissions. A higher figure could be accepted for transportation fuel CO₂ offsets as there is no technology alternative currently proposed for transportation carbon capture. The current price of one ton of CO₂ emissions credit in the EU cap and trade system is approximately \$30. This technology could participate in such a cap and trade system if it is implemented in the US/California. The price of these credits will be market driven and subject to the demand and supply in any future system. Such prices could be substantially higher or lower than the current EU price.

Calculations:

Table 1 summarizes the costs effectiveness calculations based on the system's prototype efficiencies [3] combined with today's H₂ prices. As shown in the table, total costs of \$281 per ton of CO₂ captured are proposed. For price competitiveness with the above sequestration credits, the unit price must be reduced as proposed in table 2.

Table 1: Base unit costs. Cost calculations per ton of captured CO₂ at 20% efficiency and at current H₂ prices.

Cost components	Cost / ton CO₂ Captured
CO ₂ capture (capital, operation and maintenance)	\$5
H ₂ (consumption of 113kg/tonCO ₂)	\$362
CO ₂ injection and storage	\$5
Recaptured electricity (1523 kWhr/tonCO ₂)	\$91 (offset)
TOTAL	~\$281

Table 2: Reduced unit costs. Cost calculations per ton of captured CO₂ at 100% efficiency and DOE targeted H₂ prices for 2017.

Cost components	Cost / ton CO₂ captured
CO ₂ capture (capital, operation and maintenance)	\$5
H ₂ (consumption of 22kg/tonCO ₂)	\$43
CO ₂ injection and storage	\$5
Recaptured electricity (304 kWhr/tonCO ₂)	\$18 (offset)
TOTAL	~\$35

As shown in table 2, the CO₂ capturing costs can be driven down to \$35 /ton CO₂ which is competitive with proposed credits and is cheaper than suggested sequestration techniques from flue gas [2]. The goals of this project are therefore to increase the energy efficiency of the CO₂ capturing process while reducing the cell's manufacturing costs by developing state of the art components and membranes.

Implementation barriers and ways to overcome them:

To be viable, the cost of carbon capture directly from the atmosphere must be within the range of expected carbon taxes or cap and trade prices (currently approximately \$30/ton in the EU). This highlights the two chief barriers – cost and regulatory policy.

Cost: Current electrochemical methods for separating CO₂ from moist air are some of the most efficient known - consuming only 250 kJ/mol of CO₂ captured. However, this is still over 10 times the theoretical limit of 20 kJ/mol, and this level of energy consumption alone would add over \$200/ton to the final cost of carbon capture – clearly unacceptable. However, near the theoretical limit, atmospheric carbon capture could cost less than \$10/ton on an energy basis.

The chief goal of this project will be to reduce the cost of CO₂ capture to an acceptable level by increasing the energy efficiency of the concentrator cell.

There are clear paths for improvement: improved membrane electrolytes, gas diffusion electrodes, and operating conditions. Over the course of the more than three decades since electrochemical carbon capture technology was first introduced, many new materials have come to the fore. None of these have been applied to the field of atmospheric carbon capture. This field is over ripe for dramatic improvement. This project will take advantage of modern and cutting edge materials and methods to improve the efficiency of the CO₂ capture membrane while simultaneously making it more robust.

Regulatory Policy: Carbon taxes and/or effective cap and trade programs are required to make this solution viable. Such a plan is already in place in the EU and it is generally expected that some form of this incentive plan will be in effect in California by 2020. Policy requirements, while necessary, are outside of the scope of this proposal.

Potential impact on Criteria and toxic pollutants:

Concentrating CO₂ from the atmosphere via an electrochemical process should not have an impact on criteria and toxic pollutants.



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References

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